ECONOMIC-PHYSICAL TRADE-OFFS IN SCHEDULING MISSILE SYSTEM CHECKOUTS

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PREFACE

This paper is concerned with a portion of RAND's study of automatic checkout equipment, which was initiated late in 1958 at the request of the Air Force. The project objective, as stated by Gen. S. E. Anderson, then commander of ARDC, was ". . . to establish the basic philosophy, concepts, and parameters for application of automatic test and checkout equipment to improve the operational readiness and employment of weapon systems." The primary activity then was to develop concepts, design methods and techniques, and decision aids to help make these test equipments and systems more effective -- in short, to help make the best use of test equipment dollars to get the best weapon system performance.

RAND Research Memorandum RM-2750, "An Omnibus of Briefing Papers on Analysis of Automatic Checkout Equipment and Aids to Its Design," contains a comprehensive description of the project results and a bibliography of the ten detailed project reports.

ECONOMIC-PHYSICAL TRADE-OFFS IN SCHEDULING MISSILE SYSTEM CHECKOUTS

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INTRODUCTION

This discussion concerns some economic aspects of the use of test equipment, particularly automatic checkout equipment, in a system context. The object of the study was to develop a method for determining preferred inspection intervals, considering both readiness and costs, at a system level.

The question of how often a system should be tested comes up early in the consideration of checkout equipment. It has a direct bearing on how much testing must be done, and utilization is one of the important factors in the decision to use manual, semi-automatic, or fully automatic test equipment. It is also important in determining how much equipment is required, and its relation to the rest of the system.

In explaining the method, I'll first show how readiness and costs are affected by the frequency of checkouts. Then I'll show one way to achieve a desirable balance between them. I'll be talking specifically about systems whose failures occur exponentially, or in a purely random fashion.

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It has been shown that many vacuum tubes, electronic piece-parts, airborne radars, fire-control systems, and air-to-air missiles have this very common failure characteristic, sometimes referred to as a constant failure rate.

READINESS

Let's consider a system that is to be maintained in a condition of static alert for a long time. If the system as a whole is subject to random failures, and we start with a good system, its survival probability will be an exponential curve, decreasing with time (Fig. 1). The particular exponential curve shown is for a system with a mean time to failure of 285 days, or about 9-1/2 months, and represents some data obtained on an early air-to-air missile.

If we have a force of, say, 100 of these systems, and they are ballistic missiles, the same curve can be used to show how many of these 100 systems are expected to be good at any time. At the end of 10 days, 3 or 4 will have failed, although we wouldn't know just which ones. By 100 days, about 30 would have failed, and so on. Now if we inspect these 100 systems each 100 days and repair the bad ones (instantaneously, for the moment) the expected number of good systems would follow the lower curve of Fig. 2. If instead of checking all 100 at once, we were to stagger the inspections so that we checked a different one each day until all 100 had been covered, and then started over again, the expected number of good systems would then be represented by the average height of the curve, or about 84 systems, compared to the extremes of 70 (just before checkout) and 100 (just after checkout) for the case where we check all of them at the same time. If we inspect and repair each 10 days instead of 100, the situation is represented by the upper curve, with an average of better than 98 systems ready, between

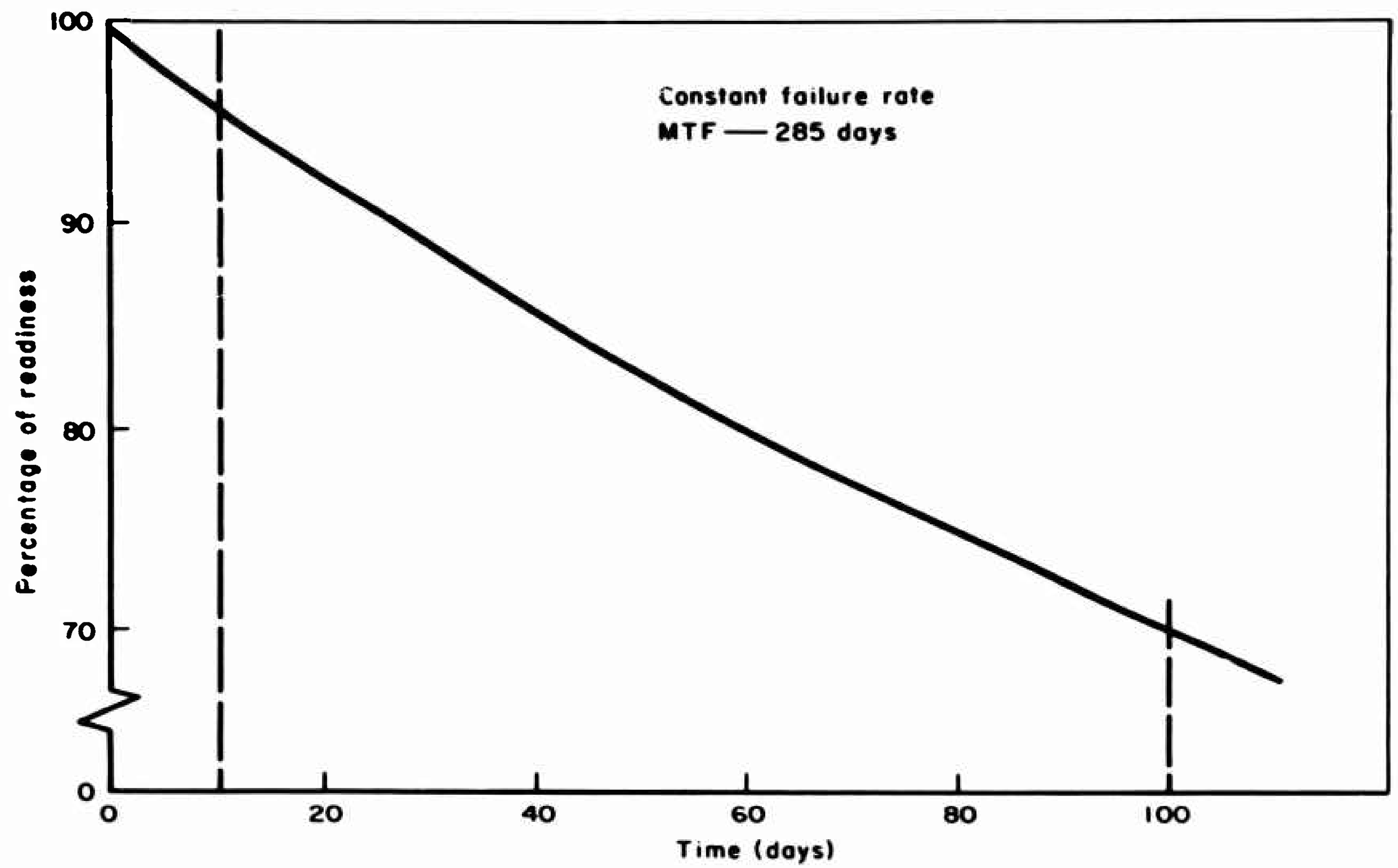

Fig.1—Readiness versus time

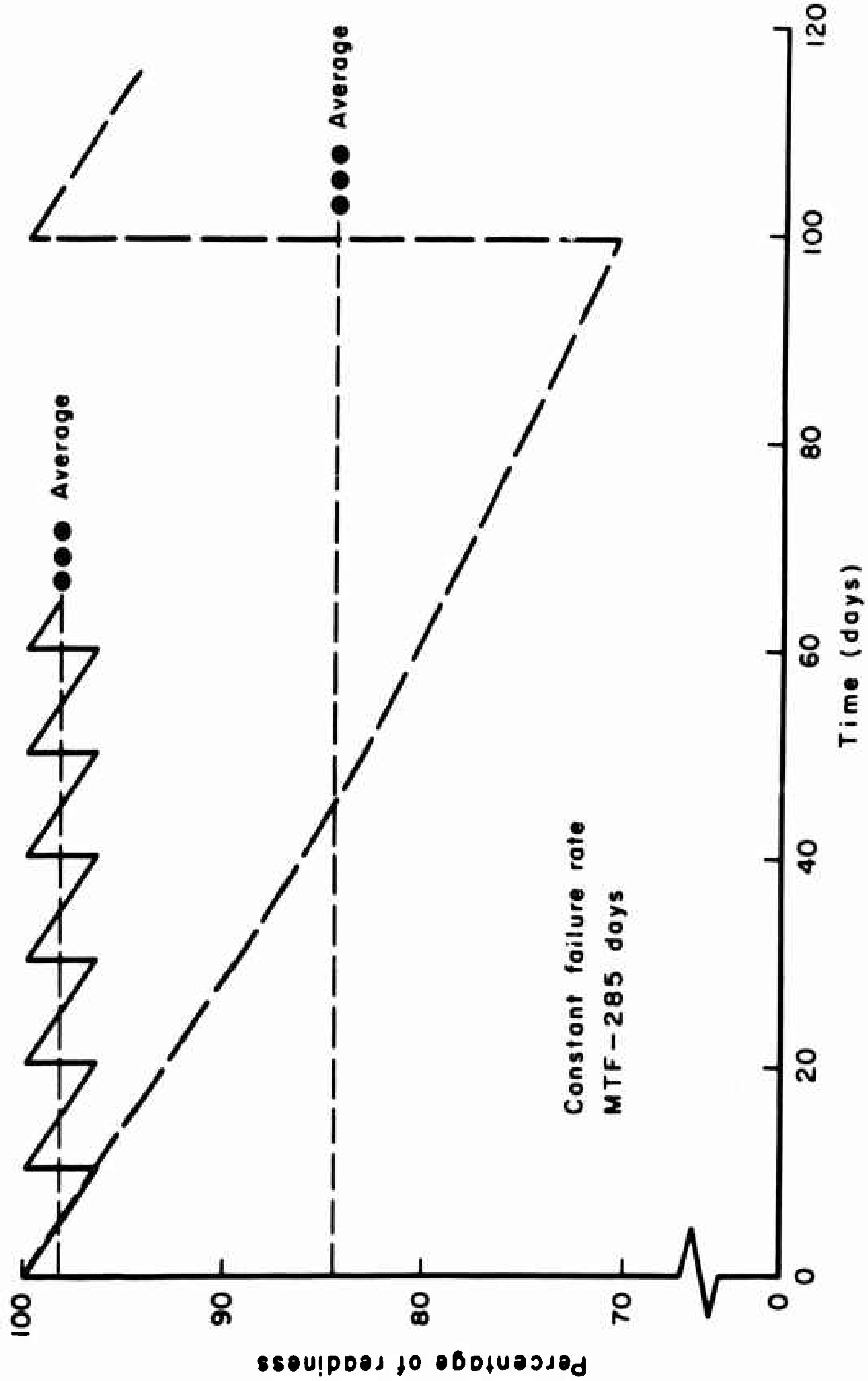

Fig. 2 — Readiness versus inspection interval

extremes of approximately 96 and 100. Inspections every 100 days give 84 per cent readiness, while inspections every 10 days give 98 per cent.

In Fig. 3, the top curve shows more clearly the relationship between the average number of ready missiles and the inspection interval (large dots indicate the two previously discussed cases). This curve indicates that we should like to inspect as frequently as possible. However, the equation represented by this curve was not the most useful or realistic one; it ignored some potentially important factors, as will be seen.

SOME IMPORTANT FACTORS

The first factor is the time required to make a repair. The second curve of Fig. 3 shows the effect of a repair time of one day. In cases where the repair time is small by comparison with the mean time to failure, the effect is not very great.

Now let's consider that the inspection activity itself can actually cause failures, in addition to discovering the ones that occurred between inspections (the so-called "tinkeritis" effect). The third curve of Fig. 3 shows how an inspection stress that causes 0.1 probability of failure affects the situation. This probability means that one time in ten, a checkout will cause a failure in an otherwise good system. Now for the first time we find that there's such a thing as checking too often, and there's some preferred interval, which in this example is 8 days, if the object is to have the most good systems.

Finally, let's also assume that the missile is out of service or off alert for 1 hour while an inspection is being made. The last curve of Fig. 3 shows some further decrease in readiness, and a slight upward shift in the preferred interval, to 9 days. Note that automatic checkout equipment

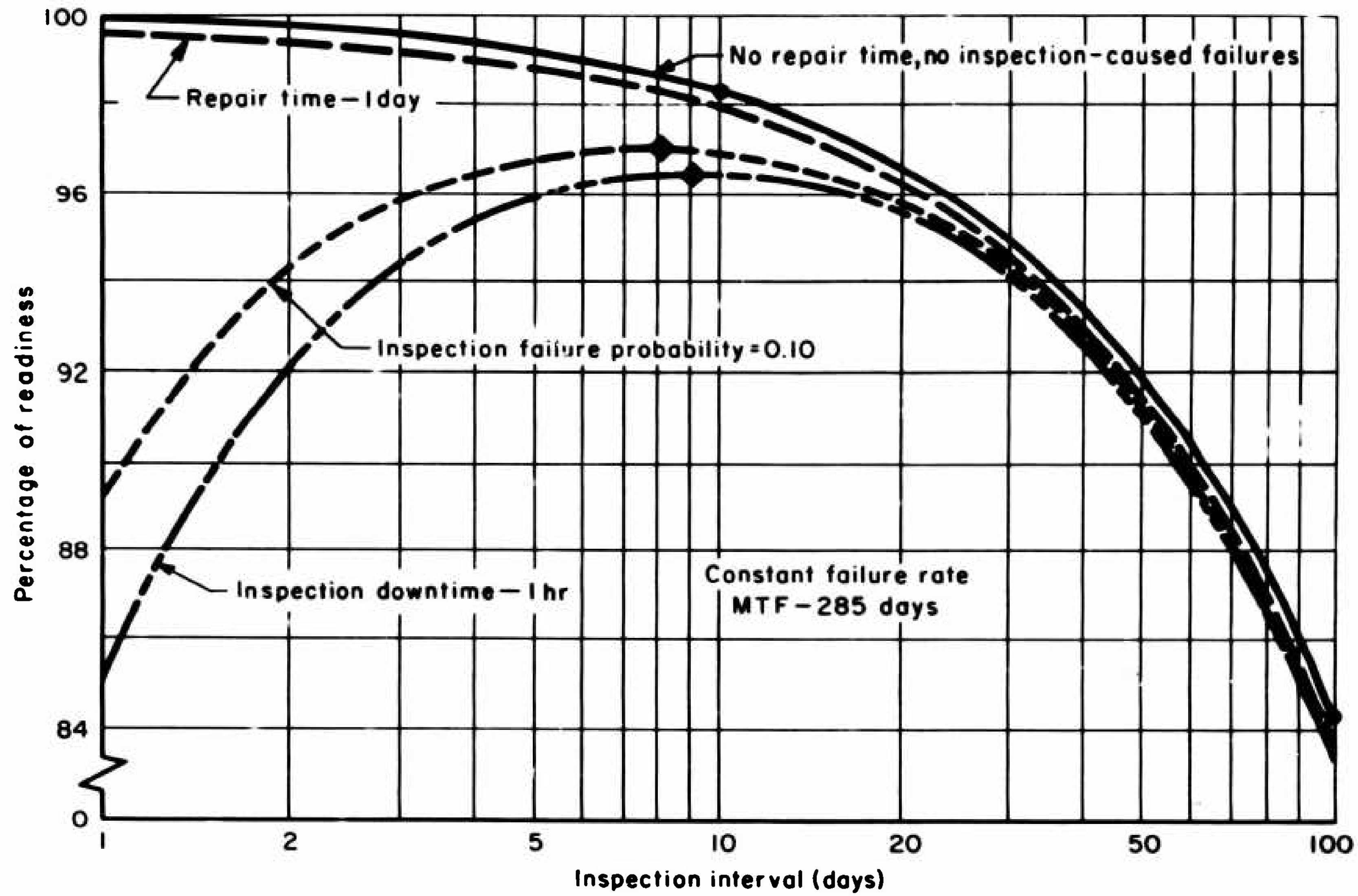

Fig. 3—Ready rate versus inspection interval

can reduce all three of these factors by means of increased testing speed. This increased speed reduces testing and repair times directly, and may also reduce the exposure to stresses during testing.

COSTS

Now let's try to find out how the checkout interval affects costs. A simple but fairly comprehensive procedure is to assume a linear cost equation. This means that each checkout costs a fixed amount of money, regardless of how many are made. Likewise, each repair costs some average amount independent of quantity. Total costs are then equal to the sum of (1) the number of inspections multiplied by the cost of each one, (2) the number of repairs multiplied by the cost of a repair, and (3) all other costs, which are presumably independent of the checkout and repair process. Incidentally, adding sophistications to this simple cost model doesn't change the results very much. Figure 4 shows costs, computed with the linear equation, as a function of time between inspections. Costs of inspection and of the repair of failures caused by inspections are closely related to the frequency of the inspections. The cost of the failures that occur between inspections also depends on the inspection interval. This is because it is assumed that only one failure can occur between inspections. (If you don't look for a failure, you don't find it and don't fix it.)

READINESS VERSUS COSTS

Figure 5 shows both readiness and cost as functions of time between inspections for an example in which the parameters are from a current Air Force system. Paradoxically, the best readiness is achieved at nearly the highest cost, and the lowest cost at the worst readiness. Moving to the right trades checkout and repair costs for extra missiles.

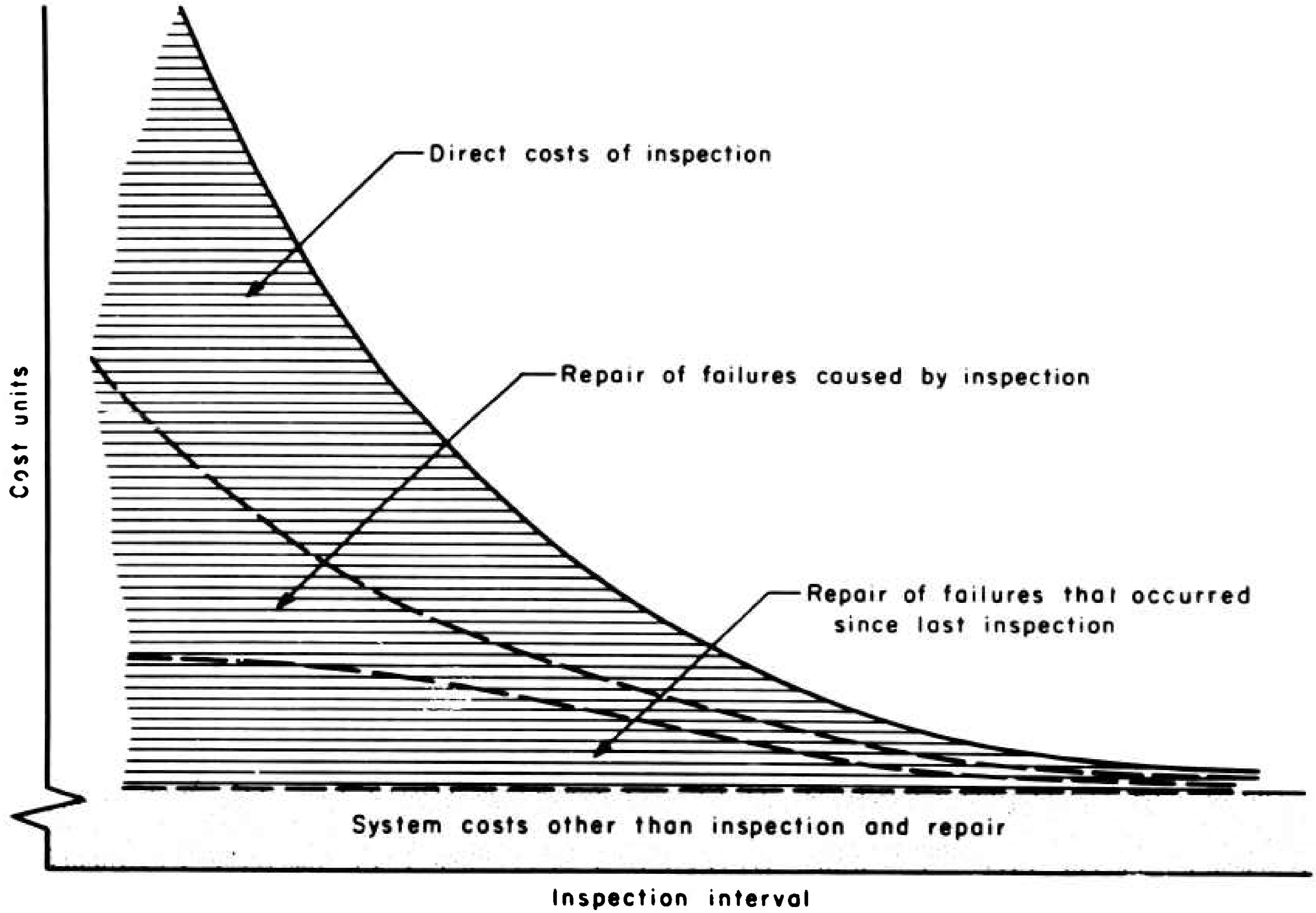

Fig. 4 — System cost versus inspection interval

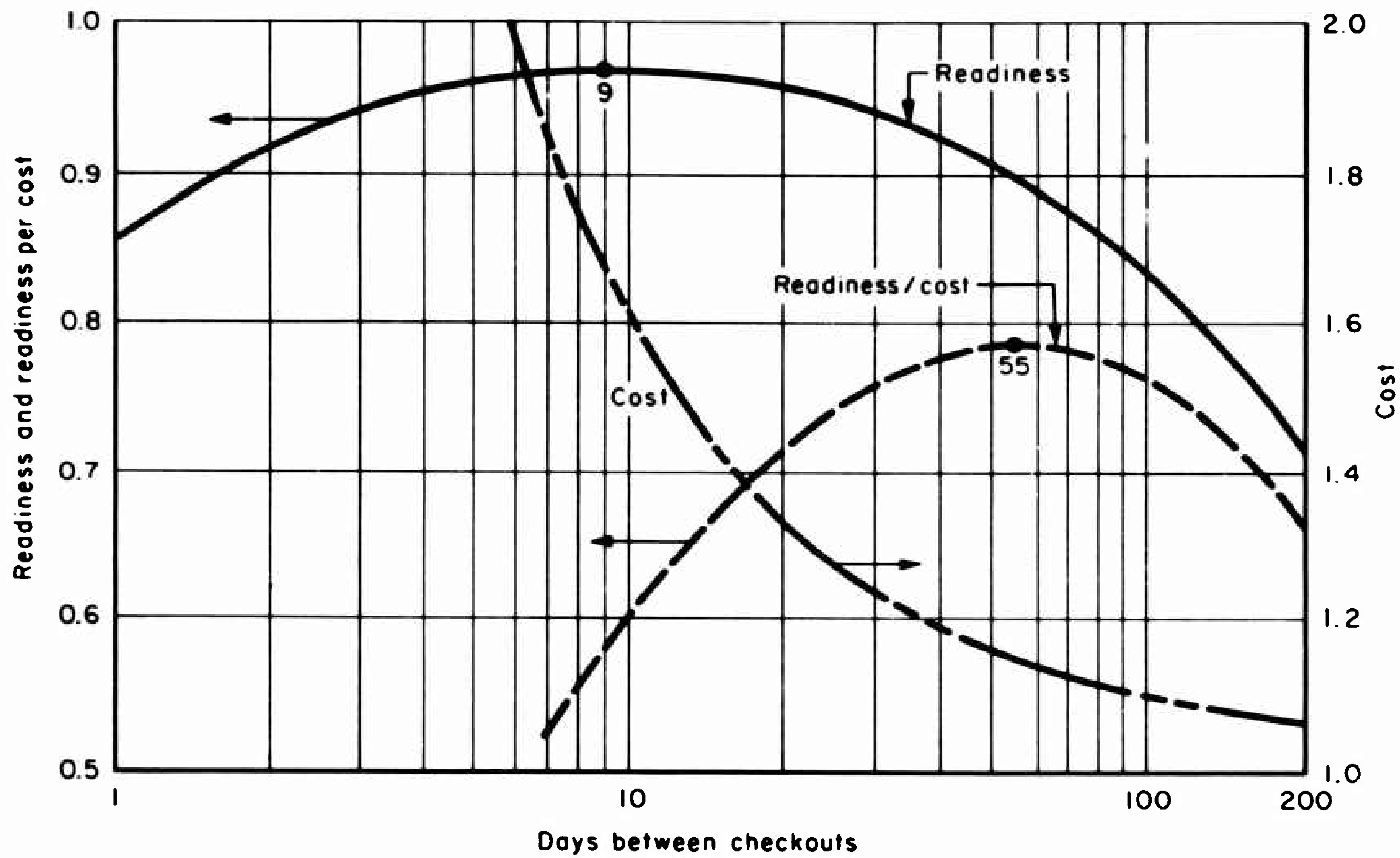

Fig. 5 — Cost, readiness, and inspection interval

The trade-off between capability (as measured here by readiness) and costs is frequently encountered in military studies. The desirable goal depends on when the analysis is made, and what restraints are placed on system planning. I used a relatively simple method for quantifying this trade-off.

THE LONG-RANGE PROBLEM

The situation which is easiest to handle and which seems to lend itself best to optimization is long-range planning for a weapon system, in which we can select not only the checkout interval, but other things, such as the number of weapons, and the capacity of the checkout and repair facilities. For this situation, two equally valid optimizing objectives can be proposed:

(1) Given a required alert capability, pick the number of weapons and the level of support that will achieve it at the lowest cost; or

(2) Given a budget limitation, choose the number purchased and the support level that will give the most alert capability.

In either case, the long-run goal is to get the most ready weapons per dollar spent.

The third curve of Fig. 5 shows how the readiness-to-cost ratio is affected by the checkout interval. The maximum, at 55 days, is achieved somewhere between the 9-day interval, which maximizes readiness and the unrealistic "never check" policy, which minimizes cost.

Three important points can be summarized here. The first is that several factors may be important in determining the preferred checkout interval. Second, there may be two "best" inspection intervals: one is the 55-day interval during normal peacetime alert; the other the 9-day interval for short periods of time during high tension or potential emergency.

This would involve lengthening work shifts and other emergency procedures. The increased cost incurred in moving toward a 9-day interval might well be borne for, say, a few weeks during a weapon's lifetime, and the temporary added capability can be as much as 6 per cent in this example. Third, you can see that if you fail to give some close attention to the frequency of inspections, you may unknowingly wander off the path in either of two damaging directions: you can end up practicing the false economy of conducting too few checkouts, in which case many of your expensive systems are useless; or you can fall into the all-too-common hazard of conducting too frequent checkouts, where you not only pay unnecessarily high costs but actually get fewer ready systems than you might otherwise.

Figure 6 shows the kind of do-it-yourself nomogram that can be used to summarize this method for determining inspection intervals as functions of the readiness characteristics and costs. It is constructed from the results of several thousand involved computations, performed on a digital computer, and permits you to use the basic method with just a little simple arithmetic. The inputs are the mean time to failure, shown along the horizontal axis, and a composite cost parameter (CP). The output here is the inspection interval that gives the most ready systems per dollar.

I'd like to point out some things about the sensitivity of the results to the accuracy of the inputs. You may be aware that cost estimates are generally inaccurate for advanced weapon systems -- usually low. Fortunately, the required estimates here are not dollar amounts, but rather the ratio of one cost to another within the system, and these are much less subject to estimating errors.

Notice that when the mean life changes a hundredfold, from 30 days to 3000, the resulting inspection interval goes up only tenfold -- from one

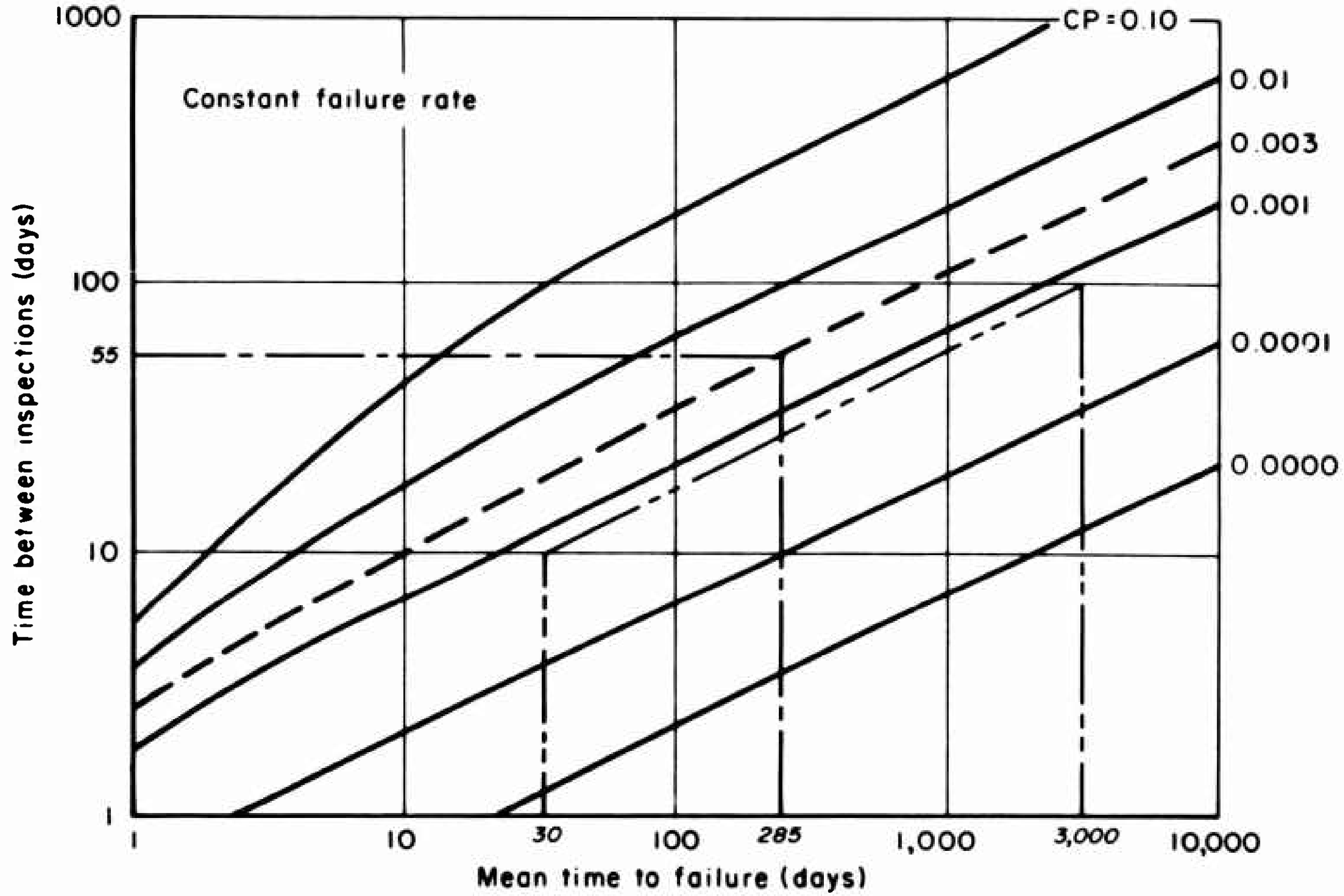

Fig. 6— Inspection interval versus failure rate and cost

day to 10, or from 10 days to 100, for example. This means that the check-out interval is relatively insensitive to errors in the estimate of mean life, and is even less sensitive to errors in any other inputs, so much so that many of them can be ignored in a diagram like this.*

PROBLEM AREAS

We will now consider some of the problem areas in using this method.

First, one must have estimates of cost and reliability, though I've implied that they don't have to be very good ones.

Budget or requirement changes, if they occur in the planning stage, have little or no effect on the determination of the best inspection intervals. However, if they occur after commitments are made for inspection and repair capacities, it may not be possible to achieve the most desirable arrangement; then one can only choose among the alternatives that still exist, and the analysis used here can be helpful for that purpose.

Other factors external to the system can also restrict the freedom to choose inspection and repair capacities, and thus prevent the implementation of the best solution. For example, disarmament agreements may limit total numbers of weapons, facilities, or manpower in some presently unknown manner.

So far, I've considered only a pre-attack situation. However, this same method can be used in an analysis that accounts for ground vulnerability and sencond-strike capability.

OTHER APPLICATIONS

This method also permits us to make comparisons of periodic and monitored checkout on a cost-effectiveness basis.* If we make some plausible

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*For more detailed treatment see Kamins, M., Determining Checkout Intervals for Systems Subject to Random Failures, The RAND Corporation, Research Memorandum RM-2578, June 15, 1960.

assumptions about the characteristics of electronics systems, for example, we can show that monitored or continuous checkout is advantageous when (1) the mean time to failure, (2) the cost of a repair, and (3) the ratio of the operating failure rate to the standing failure rate are all relatively low. They are most likely to be low in relatively unreliable subsystems (low mean time to failure), which are modularized (for ease of repair), and use solid-state components with generous derating (so that operating stresses are not much higher than standing stresses).

The method as described was developed for a complete weapon system, but can also be applied to portions of a system.